SCHEMATIC DESIGN REPORT

Tundra Wetland Sewage Treatment System Design

Qamani'tuaq (Baker Lake), Nunavut

Department of Community and Government Services, Government of Nunavut.

PROJECT NO. 1040316

Jacques Whitford AXYS

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REPORT TO: **Department of Community and Government Services**
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ON: **Schematic Design**
Tundra Wetland Sewage Treatment System
Qamani'tuaq (Baker Lake), Nunavut

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EXECUTIVE SUMMARY

Nunami Jacques Whitford Ltd. (NJWL) was retained by the **Department of Community and Government Services (**CGS) of the **Government of Nunavut** (GN) to prepare a schematic design report for a Tundra Wetland Sewage Treatment System in Qamani'tuaq (Baker Lake), Nunavut. This report presents the schematic design for review by CGS.

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1.0 INTRODUCTION

Nunami Jacques Whitford Ltd. (NJWL) was retained by the **Department of Community and Government Services** (CGS) of the **Government of Nunavut** (GN) to prepare a schematic (conceptual) design report for a Tundra Wetland Sewage Treatment System in **Qamani'tuaq** (the Hamlet or Baker Lake), Nunavut. The design and subsequent implementation is intended to enable CGS and the Hamlet to fully understand the design, approve the design, and achieve compliance with effluent quality standards in its most recent Water Licence issued by the **Nunavut Water Board** (NWB). The comments received from CGS and the Hamlet will provide the direction necessary to proceed to the detailed design stage and to submit an application to renew the Hamlet's Water Licence, which regulates water use and waste disposal in the community. The next stages in the project will involve detailed design, submission of the water license application and tendering of the physical works. Construction is expected to occur in fiscal year 2009.

This report (Report) is organized as follows: Section 2 provides background information about the Tundra Wetland and sewage generation forecasts for Baker Lake. Regulatory requirements are identified in Section 3. A preliminary (conceptual) design option is presented in Section 4, followed by a schematic design of the proposed option in Section 5 and conclusions and recommendations in Section 6. The Appendix contains preliminary figures.

2.0 BACKGROUND

2.1 Community Information

The **Hamlet of Qamani'tuaq** (Baker Lake or the Hamlet) is located north of the mouth of the Thelon River on the northwest shore of Baker Lake in the Kivalliq region of Nunavut. The geographic coordinates of the community are 64^0 18' N, 96^0 03' W. The location of the community is presented in **Figure 1** in Appendix A. Baker Lake itself is the fifth largest lake in Nunavut, with a surface area totaling 1,887 square kilometers (km) and measuring approximately 91 kilometers from the mouth of the Thelon River to the Bowell Islands and Narrows in the east end (Natural Resources Canada, 2004).

The Hamlet is located in the Wager Bay Plateau Ecoregion of the Northern Arctic Ecozone. The region is characterized by broad sloping uplands, plains and valleys. Soils are primarily silty sand and silty clays overlying boulder till, beach deposits and reworked till. Local topography slopes upward from the lake to a ridge approximately two kilometers to the north. A site overview of the existing conditions is provided on **Figure 2** in Appendix A. Permafrost is present, with the active layer established at up to 1.5 meters in depth. Vegetation in the area is typical tundra vegetation consisting of mosses, lichens, grasses, and dwarf shrubs.

The average annual precipitation in the Hamlet consists of 156 millimeters of rainfall and 1,307 millimeters of snowfall, resulting in an annual total of approximately 287 millimeters of equivalent precipitation presented as rain. The July mean high and low temperatures are 16°C and 6°C, respectively. The July and August average daily temperature is about 11°C. The January mean high and low temperatures are -28.7°C and -35.8°C, respectively. The January average daily temperature is -32.3°C. Winds are commonly from the north at an average speed of 23 km/h.

The population of the community was estimated at 1,744 in 2007, based on **Statistics Canada**, Demography Division, prepared by the **Nunavut Bureau of Statistics**, May 2008. Economic activities include public services, mineral exploration, and arts and crafts. The level of mineral exploration activity around the Hamlet has increased significantly over the last two years. In September 2006, **Cumberland Resources** announced their intention to construct the Meadowbank Gold Mine 110 km northwest of the Hamlet.

Electrical services are provided by the **Nunavut Power Corporation**, while the Hamlet provides trucked water, sewage and waste disposal services. Baker Lake has regularly scheduled air service, however, most supplies arrive annually by barge during the open water period.

The Hamlet draws its drinking water from Baker Lake and trucks it to users throughout the community.

The Tundra Wetland Sewage Treatment System was put into operation in 1980, and it is shown on **Figure 2** of Appendix A. Sewage is collected from the Hamlet's houses and other buildings by truck and discharged into a holding cell (the Holding Cell) located approximately 1.2 kilometers north of the community. In communities where water delivery/sewage collection is by truck, the ratio of residential to commercial/industrial input is very high. Sewage composition is essentially "domestic" in nature. **Table 1** presents Baker Lake's average wastewater composition reported in Dillon's 1995 report "*Sewage Treatment Using Tundra Wetlands*".

Table 1: Existing Average Wastewater Composition

Parameter	**Concentration**
Fecal Coliforms	$1.5X10^{8}$CFU/L (colony forming units/Liter)
BOD_5	383 mg/L
TSS	365 mg/L
Oil and Grease	No visible sheen
pH	7.5
Ammonia	72 mg/L

The Holding Cell has an area of approximately 500 square meters. Its berms are not impermeable and effluent seeps through them by exfiltration. At times there is overtopping of the berms. The sewage flows down a slope for approximately 200 meters before entering Lagoon Lake. From Lagoon Lake, sewage flows east approximately 300 meters into Finger Lake, and then another 1,000 meters from Finger Lake to the inlet of Airplane Lake. Compliance with Water Licence effluent criteria is to be achieved at Surveillance Network Program [SNP] Station P3 (aka Compliance Point BAK-2 and Monitoring Station 1191-2) located at the inlet to Airplane Lake. Airplane Lake drains south approximately 1,300 meters and effluent from it enters Baker Lake.

A solid waste disposal facility was constructed in 1991 on the south shore of Finger Lake, adjacent to the sewage treatment system. Solid waste is collected on a scheduled daily basis from the community and transported to the landfill by truck. Separate disposal areas are provided for bulky and hazardous wastes and waste oil. The site was expanded and modified in 1998 to improve compliance. Runoff from the solid waste disposal facility enters the sewage treatment system at Finger Lake.

2.2 Sewage Generation Rates and Forecast

System analysis and design requires the projection of wastewater generation rates for a 20-year planning horizon. The Nunavut Bureau of Statistics has estimated a population of 1,744 for Baker Lake in 2007. **Table 2** illustrates population projections for the Hamlet of Baker Lake for a 20 year period, based on an annual increase of 2 percent, as projected by the Nunavut Bureau of Statistics.

Table 2: Population Projections- Baker Lake, Nunavut

Year	Population
2009	1,814
2014	2,003
2019	2,212
2024	2,442
2029	2,696

Projected sewage generation rates for the period between 2009 and 2029 are shown in **Table 3**. Sewage volumes are anticipated to be equal to water consumption volumes. The annual sewage generation is projected, based on a per capita water consumption rate of 100 Liters per capita per day (L/c/d.). To facilitate annual ice storage, the volume of sewage produced during a ten-month (300-day) period each year is included in the table.

Table 3: Sewage Generation Projections – Baker Lake, Nunavut

Year	Population	Annual Water Consumption (L)	Annual Sewage Volume (m^3)	10-Month Sewage Volume (m^3)
2009	1814	66,227,702	66,228	54,434
2010	1851	67,552,256	67,552	55,522
2011	1888	68,903,302	68,903	56,633
2012	1926	70,281,368	70,281	57,766
2013	1964	71,686,995	71,687	58,921
2014	2003	73,120,735	73,121	60,099
2015	2043	74,583,150	74,583	61,301
2016	2084	76,074,813	76,075	62,527
2017	2126	77,596,309	77,596	63,778
2018	2168	79,148,235	79,148	65,053
2019	2212	80,731,200	80,731	66,354
2020	2256	82,345,824	82,346	67,681
2021	2301	83,992,740	83,993	69,035
2022	2347	85,672,595	85,673	70,416
2023	2394	87,386,047	87,386	71,824
2024	2442	89,133,768	89,134	73,261
2025	2491	90,916,443	90,916	74,726
2026	2541	92,734,772	92,735	76,220
2027	2591	94,589,467	94,589	77,745
2028	2643	96,481,257	96,481	79,300
2029	2696	98,410,882	98,411	80,886

2.3 Review of Background Information

Several documents were made available to NJWL as background to the current study. Key findings from these materials are reported below, as follows:

Type "B" Water Licence for N6L3-1191 (Renewal), Northwest Territories Water Board, September 1993

Licence N6L3-1191, a renewal Type "B" Water Licence was issued to the Hamlet of Baker Lake for the period of September 1, 1993 to August 31, 1999. A number of general conditions are included in the licence, as well as specific conditions pertaining to water use, waste disposal, abandonment and restoration, and operation and maintenance. The licence establishes sewage effluent quality standards to be met at Surveillance Network Program (SNP) Station 1191-2, identified in the licence as "run-off below the Waste Disposal Facilities (exact location to be determined following a study required in the licence)." The location of this station was subsequently recommended to be located where water from the wetland enters Airplane Lake. Two SNP stations were identified, with one at the pump house (1191-1) and one at the run-off below the waste disposal facility (1191-2). Parameters required to be analyzed on a monthly and annual basis were also specified.

Sewage Treatment Using Tundra Wetlands, Dillon Consulting Limited, 1999

Dillon Consulting Limited (Dillon) undertook a review of three existing wetland sewage treatment systems in Nunavut, including that for the Hamlet of Baker Lake, to develop a better understanding of the sewage treatment capabilities of natural wetlands in northern Canada. The study involved a review of pertinent literature, characterization of the three wetlands, and collection and analysis of effluent samples. Key findings for the Hamlet of Baker Lake are summarized as follows:

- During the sampling period (spring and summer 1996) the Tundra Wetland achieved removal rates for analyzed parameters equal to or better than expected from an annual storage lagoon;

- When temperatures are below freezing (October to May), a sewage ice pack forms on the slope of the valley walls up-gradient of Lagoon Lake. Observations indicated that the ice melts over a period of approximately four weeks;

- The mass of fecal coliforms coming from the melting ice pack was minimal, likely due to die off through freeze/thaw action. Data also suggested a slight reduction of BOD_5 from the melting ice pack;

- The addition of a primary treatment lagoon would hold the melting ice pack and reduce loading to the system during the spring melt period, allowing for a controlled discharge over time;

- Analytical data suggested that nutrient removal increased with treatment distance, time and increased hydraulic retention; and

- There was a perception, as identified in a Traditional Environmental Knowledge Study, that the wetland treatment system would not protect the aquatic environment in the future and, therefore, might impact the flora and fauna of the area.

Baker Lake Sewage and Solid Waste Disposal Operation and Maintenance Manual, Dillon Consulting, 1999

This manual was prepared as a requirement of the Hamlet's Water Licence and is intended to assist the Hamlet in operating its waste disposal facilities in compliance with its licence. The manual provides a general overview of the sewage and solid waste disposal systems in the community, including sketches of the general layout of both facilities. The manual provides general instructions for the operation and maintenance of each facility, including recordkeeping and effluent sampling according to license requirements. A spill contingency plan for spills occurring at the landfill is appended in the manual.

Water Licence for NWB3BAK9904 (Renewal of NWT Licence N6L3-1191), Nunavut Water Board, June 1999

The Nunavut Water Board issued Water Licence NWB3BAK9904 to the Hamlet of Baker Lake, for a five year period, effective October 1, 1999. This licence is a renewal of Water Licence N6L3-1191, issued by the NWT Water Board prior to territorial division. Licence requirements include the submission of annual reports, preparation of an operation and maintenance (O & M) manual, a spill contingency plan, and an abandonment and restoration (A & R) plan; operating a surveillance network program; posting of signs indicating the location of facilities and sampling locations; and maintenance of all licenced facilities.

Four Surveillance Network Program (SNP) stations were identified-BAK-1 (formally 1191-1), BAK-2 (formally 1191-2), BAK-3 (formally 1191-3) located at the outlet of Airplane Lake, and BAK-4 located at the runoff from the solid waste disposal facility at Finger Lake. Specified sewage effluent quality criteria are to be met at Station BAK-2.

Water Licence Inspection Report, Indian and Northern Affairs Canada (INAC), November 2001

The Water Resources Division of **Indian and Northern Affairs Canada** (INAC) conducted a water licence inspection in August of 2001. The inspection addressed five different topics: potable water, sewage lagoon, landfill, waste oil, and non-compliance. In addition, a number of water and effluent samples were taken at the Surveillance Network Program (SNP) stations. The water licence inspection report highlighted the following:

- There was evidence of erosion of the sewage Holding Cell berms and preventive maintenance was recommended;

- The solid waste site was reported to be efficiently managed with proper waste segregation being practiced;

- There was a lack of evidence that a former waste oil pit had been properly contained, resulting in the potential for hydrocarbon contamination of water. Hydrocarbon contamination was noted at current waste oil storage site;

- Analysis of an effluent sample from Station BAK-2 indicated compliance with all licence and *CCME Protection of Freshwater Life* parameters, except iron. Furthermore, a Microtox analysis did not attribute toxicity to runoff from solid waste facility;

- Analysis of a raw water sample from the vicinity of drinking water supply (Station BAK-1) indicated compliance with all parameters of the *Guidelines for Canadian Drinking Water Quality*;

- Required signs had not been posted; and

- The licencee had not submitted the required annual reports, operations and maintenance plan, spill contingency plan, and abandonment and restoration plan.

Water Licence Inspection Report, Indian and Northern Affairs Canada (INAC), November 2002

The Water Resources Division of INAC conducted a Water Licence inspection again in July 2002. The inspection addressed the same items reviewed in 2001. The Water Licence inspection report highlighted the following:

- Analysis of a raw water sample from the vicinity of drinking water supply (Station BAK-1) indicated compliance with all parameters of the *Guidelines for Canadian Drinking Water Quality* with the exception of slight exceedences for color and turbidity;

- The sewage Holding Cell appeared to be ineffective in reducing suspended solids (TSS) from reaching the wetland. However, effluent was reported to have undergone considerable treatment prior to reaching Airplane Lake (Station BAK-2);

- Samples of seepage from the landfill (Station BAK-4), indicated total ammonia, turbidity, total suspended solids and BOD were in excess of *Municipal Wastewater Effluent Quality Guidelines*;

- Waste oil drums were observed in the ditch and associated leaking of oil had occurred. Stained soil was observed;

- Secondary containment for waste batteries was recommended;

- Wastes were poorly segregated in the bulky metal waste area;

- Required signs had not been posted; and

- The licencee had not submitted the required annual reports or the operations and maintenance plan.

Water Licence Inspection Report, Indian and Northern Affairs Canada (INAC), November 2003

The Water Resources Division of INAC conducted a third Water Licence inspection in August of 2003. The inspection addressed the same items reviewed in 2001 and 2002. The Water Licence inspection report highlighted the following:

- The drinking water source is not identified with signs. There is a significant amount of traffic on the lake which presents potential for contamination;

- Station BAK-1, the drinking water intake, was sampled and all results were within licence guidelines and the **Canadian Council of Ministers of the Environment** (CCME) *Drinking Water Quality Guidelines*;

- There was evidence that the berms on the Holding Cell had been breached and it was observed to be discharging continuously, despite the repairs to the berm;

- Stations BAK-2, BAK-3, and BAK-4 were sampled. BAK-2 exceeded guidelines for total iron and phenol, BAK-3 samples were within guidelines (however, iron levels were only slightly less than the guideline), and the results for the BAK-4 sample greatly exceeded the CCME guidelines for iron, suggesting that leachate from the old landfill may be affecting the water quality at this station;

- There is a lack of containment for hazardous materials at the solid waste landfill and runoff into Finger Lake is a concern; and

- Numerous non-compliance issues related to reporting and submission of plans were identified.

Site Investigation Report for the Sewage Disposal System in the Hamlet of Baker Lake, September 2005

Community and Government Services (CGS) completed a site investigation of the Tundra Wetland System to evaluate its effectiveness and compliance with Water Licence requirements and federal water quality guidelines. Three sampling events were undertaken in 2005, with sample locations including Lagoon Lake (P1), Finger Lake (P2), Airplane Lake (P3) and the mouth of Garbage Creek at Baker Lake (Pfd). Observations and conclusions of the investigation were:

- Effluent was observed to seep out of the Holding Cell, traveling down slope to Lagoon Lake;

- Water in Lagoon Lake and Finger Lake appeared green, likely due to an algal bloom resulting from nutrients in the effluent;

- There was thick and abundant vegetation as well as various bird species and small fish in the third lake (Airplane Lake);

- The proximity of the landfill to the Tundra Wetland System raises the potential for leachate from the landfill to enter the system and negatively affect effluent quality;

- Analytical results of samples from all three events indicated compliance with Water Licence effluent quality criteria and most federal criteria by the time effluent reached Finger Lake (P2). The exceptions were elevated copper, iron, and zinc, possibly an influence from landfill leachate; and

- Discarded metal drums at the current and previous landfill sites and the lack of signage throughout the system were noted as an issue of concern.

2.4 Nunami Jacques Whitford 2007 Site Investigations

NJWL personnel conducted site visits at the Hamlet in 2006 and 2007 to confirm previous observations about the existing Tundra Wetland Sewage Treatment System. The 2006 site visits are summarized in an Interim Report dated December 4, 2006. The July 3, 2007 site visit is reported below as follows:

A tour of the wetland site and landfill area was given by Hugh Ikoe and he explained what everything was and explained the landfill situation.

The Holding Cell area is very small. Examination of the Holding Cell's downslope dike showed that water was seeping out of the middle of the north base of the dike. The water was seeping at a fairly rapid rate. There was evidence of significant erosion of material that had been piled on the north side of the dike.

Recommendation: Place a plastic liner in the Holding Cell to prevent water from seeping through its berms. With the materials that appear to be available in the area, it would be very difficult to provide impervious materials such as clay for a liner that would be suitable for holding back the water. Indeed, it appears that any efforts that might be made to prevent water from leaking from the cell by addition of materials would ultimately instead contribute more sediment to the system downstream of the Holding Cell.

After the water discharges from the Holding Cell, there are two main channels that water flows in. These channels separate in a few places, creating multiple channels that flow into Lagoon Lake. There was ice that had formed over the winter at the inlet zone to Lagoon Lake, indicating that water continued seeping from the Holding Cell through the winter. There was evidence of solids on the ice and on the grasses in the wetland area between the holding cell and Lagoon Lake. There was also evidence of more significant flow, presumably from during the major spring melt period. Grasses were matted down and covered with solids. Evidence of FOG (fats, oil & grease) was also present in the small puddles of water off of the main flow channels.

Recommendation: Provide additional filtration of water prior to its discharge to Lagoon Lake. Additional filtration would prevent some of the major sediment transport that is occurring. This sediment transport is contributing to turbidity in the water and nutrient transport downstream. Filtration might be implemented via pervious dikes that would serve three purposes: 1. attenuate flow and spread it out evenly over the area, 2. filter water, and 3. provide a medium in which bacteria would grow and help start treating water prior to its discharge to Lagoon Lake.

Two potential locations for a new flow attenuation dike were entered into the GPS. There were also odours present in the area between the Holding Cell and Lagoon Lake, even with the wind blowing out of the northwest. In Lagoon Lake, there was algae growth evident along the shore. There were also ducks present in the lake. Bluebills and Oldsquaw were seen in Lagoon Lake. They were diving for food and appeared to be nesting in the area.

The channel between Lagoon Lake and Finger Lake had significant algae growth on rocks in the channels and in the pools off the main channel. There was evidence in this area as well of more significant flow previous. As the water receded, the pools that were left have evidence of solids and FOG as well as algae growth.

Recommendation: Another flow attenuation dike would also be beneficial in the channel between Lagoon Lake and Finger Lake. GPS coordinates were taken of what appears to be a good location for such a dike. This dike should also be a pervious dike to spread out the flow and provide treatment through bacterial growth.

The entire channel between Lagoon Lake and Finger Lake had significant algae growth. There was an area with snowpack still left north of the channel. The snow was melting and water was filtering through the tundra to the channel. None of these pools and channels had any algae growth in them. The water was crystal clear and had no evidence of sediment transport, indicating that the algae growth and the turbid water are being created from the Holding Cell discharge.

At the discharge into Finger Lake, there was a pool with algae growth. There were no odours evident at this location. Examination of the area between the solid waste dump and Finger Lake showed pools of water with significant algae growth and evidence of hydrocarbons on their surfaces. These pools were above the high flow elevation of the discharge channel between Lagoon Lake and Finger Lake. It appeared that the contamination and nutrients were coming from leachate from the solid waste facility.

Recommendation: The leachate from the solid waste facility should be diverted and treated prior to discharge into Finger Lake. This could be done by routing the piping to the east and creating a lagoon, or by building a long permeable dike to provide treatment and flow attenuation. As was the case at Coral Harbour, the wetland system will also have to treat leachate and any new lagoon would be a part of it.

Around the south shore of Finger Lake, there was algae growth. There were also a large number of birds using Finger Lake. Greater and lesser bluebills, Oldsquaw, white fronted geese, Canada geese, northern pintails, green wing teal, sandhill cranes and seagulls were all present.

The channel between Finger Lake and Airport Lake had algae growth along the entire reach of the channel. This channel was well defined and contained a series of rapids and pools. The rapids were providing aeration of the water and the pool areas contained more submergent vegetation and algae. There was evidence in this channel that there had been higher flows earlier in the year during snowmelt. There were algae growing in the side pools left behind, although its growth not as significant as that in the upstream channels. There were fewer algae closer to Airport Lake.

At the discharge to Airport Lake, the water had a green tint to it. There was also algae growth on the rocks at the discharge location. At the discharge of Airport Lake, there were very little algae present.

In July 2007, a project engineer from **Jacques Whitford NAWE** (formerly North American Wetland Engineering) visited the Hamlet of Baker Lake to further delineate wastewater and landfill leachate flows and to collect additional information for the design of structures to enhance the Tundra Wetland System for improved wastewater treatment. The results of the site visit and associated recommendations were presented in the *Hamlet of Baker Lake Report of the Environmental Study and Evaluation of the Water and Sewage System*, dated October 15, 2007. However, regarding the landfill, an examination of the area between the current solid waste facility and Finger Lake revealed pools of water located above the high flow elevation of the channel between Lagoon Lake and Finger Lake. These pools had significant algal growth and evidence of hydrocarbons on the pool surfaces. It was apparent that contamination and nutrients were entering Finger Lake from the solid waste facility.

2.5 Summary

The Hamlet of Baker Lake has been discharging sewage effluent in the same location since at least 1980. Effluent leaches from the Holding Cell and flows over the tundra. The treatment performance of the Tundra Wetland Sewage Treatment System has been subject to numerous studies since 1993. All investigations generally supported that the Tundra Wetland System was effectively treating the sewage and could continue to do so in the future. Review of analytical data from samples collected annually throughout the system indicates that the wetland is currently treating sewage effluent to effluent quality standards contained in the Hamlet's Water Licence.

3.0 REGULATORY REQUIREMENTS

Water licences issued by the Nunavut Water Board include requirements for sewage and solid waste disposal. A typical municipal Water Licence includes sewage effluent criteria for Fecal Coliforms (as colony forming units per Liter (CFU/L)), Biochemical Oxygen Demand (BOD_5), Total Suspended Solids (TSS), oil & grease, and pH. Effluent quality standards contained in the current Water Licence are presented in **Table 4**.

Table 4: Current Licence Effluent Quality Standards

Parameter	Maximum Average Concentration
Fecal Coliforms	$1X10^5$CFU/L
BOD_5	80 mg/L
TSS	100 mg/L
Oil and Grease	No visible sheen
pH	Between 6 and 9

The Canadian *Water Quality Guidelines for the Protection of Aquatic Life* applies to the discharge of the effluent from the last control point of the Hamlet's sewage treatment system. A critical contaminant addressed in these guidelines is ammonia. Evaluation of the treatment capacity of the Baker Lake Tundra Wetland should take into account these requirements with compliance assessment relative to the most stringent values. In addition to the above requirements and the future Water Licence of the Hamlet, effluent from the Hamlet's wastewater treatment system should not be toxic to fish. Based on the analytical results from effluent samples, it is evident that current and anticipated discharge criteria can be achieved at the proposed compliance point P3 (Airplane Lake).

4.0 DESIGN IMPROVEMENTS

The purpose of the facility design presented herein is to enable the Hamlet of Baker Lake to achieve compliance in the 20 year design period with the sewage effluent quality standards contained in the Water Licence issued by the Nunavut Water Board. The top four technologies for preliminary comparison were storage lagoons, zero discharge lagoons, wetlands sewage treatment and treatment in sequencing batch reactors (SBRs, a type of mechanical activated sludge wastewater treatment plant). Since storage lagoons need a 2-year detention time for small communities, zero discharge lagoons are not applicable to the Kivalliq Region, and SBRs are both too expensive and labor extensive, the option selected, that with the lowest present worth cost, is a wetlands sewage treatment system with winter retention lagoons.

4.1 Improve Storage Lagoon

Storage and treatment lagoons are a common method for treating sewage in northern communities. Following a typical northern lagoon storage and release regime of 10 months (300 days) storage and release in the late summer/fall, the sewage holding cell or lagoon at Baker Lake would have to have a capacity of 80,886 cubic meters to address the 20 year planning horizon ending in 2029, as shown in **Tables 2 and 3**. For Baker Lake, the design flow is the total annual sewage (98,411 cubic meters per year) divided by the release period (65 days per year) 1,514 cubic meters per day.

The dimension of the existing Holding Cell is approximately 31 meters by 9 meters, or about 280 square meters. The area of Lagoon Lake, at elevation 56.3 meters above sea level (masl), is about 17,000 square meters. Allowing for reduced capacity due to the interior side slopes on the berms and the fact that Lagoon Lake is frozen during the required sewage volume timeline, the estimated storage capacity of the Holding Cell and Lagoon Lake is much less than that which would be needed.

The size of a storage lagoon sized to meet future demand would be approximately 235 meters by 235 meters (55,225 square meters), with a 1.5 meter depth. To increase the effective storage volume upstream of Finger Lake, and assist in treating the leachate before it flows into Finger Lake, the addition of berms perpendicular to the flow between Lagoon Lake and Finger Lake would increase the storage volume available. To allow the Lagoon Lake "storage lagoon" to function as a typical lagoon new berms should be constructed such that permafrost will permeate or migrate into the berms and present an impervious barrier. Two berms constructed to a minimum elevation of 58.0 thereby providing adequate storage to meet the Hamlet's future needs. The available storage, from existing grade to elevation 58.0 masl in the vicinity of Lagoon Lake, is adequate to meet the 20 year (2029) demand of 80,886 cubic meters. A recently tendered Tundra Wetlands Upgrade project is underway to enclose the area in the vicinity of Lagoon Lake including the area below elevation 58.0 masl, and the Holding Cell area, within a fence.

The existing Holding Cell can be improved and increased in size. Re-design of its berms can inhibit water from flowing directly to Lagoon Lake. In addition, a second holding cell might be constructed west of the existing cell. Adding berms downstream of these two holding cells would aid in spreading out the flow towards Lagoon Lake. The berms would be constructed perpendicular to the flow direction and designed such that permafrost would permeate or migrate into them, creating impervious barriers.

A schematic of the size increase to the existing Holding Cell, the location of a second holding cell, berm sizes and locations for further new berms downstream of the holding cells, berm sizes and locations downstream of Lagoon Lake is presented on **Figure 3** in Appendix A.

4.2 Reduction of Fecal Coliforms

For most of the year, the sewage is discharged towards Lagoon Lake in sub-zero temperatures and freezes. Freeze-thaw action is effective for destroying fecal coliforms. Freezing will rupture bacterial cells and results in their death, which eliminates the potential for infection. Due to the melting of frozen sewage, flows from the sewage disposal area will be higher during the melt period than during the frozen period. However, the quality values of the sewage should be lower as melt period sewage dilutes with and thaws out sub-zero temperature period sewage. For purposes of this evaluation, it was assumed daily influent sewage has a fecal coliforms value of $1.5X10^8$ CFU/L. However, this frozen sewage fecal coliforms value drops to negligible levels as the sewage freezes. Therefore, when the frozen sewage thaws and mixes with the daily influent sewage during the un-frozen period, a weighed fecal coliforms value of $2.67X10^7$ CFU/L is obtained ($1.5X10^8$ CFU/L X 65 days / 365 days).

Numerous studies have shown that the removal of fecal coliforms in lagoons depends on detention time and temperature, and can be modeled (*Natural Wastewater Treatment Systems*, Crites, Middlebrooks, Reed, 2006) using values given in **Table 1** to estimate the level of coliforms after the lakes as follows:

$$C_f = C_i / (1 + t(k_T))^n$$

where

C_f = Effluent fecal coliforms (CFU/L),
C_i = Influent fecal coliforms (CFU/L), $2.67X10^7$ CFU/L
t = Detention time in the cell (d), equal to 54 days [81,500m^3 / 1,514 m^3 / day]
k_T = Temperature-dependent rate constant (d^{-1}), equal to $(2.6)(1.19)^{(Tw-20)}$, $(2.6)(1.19)^{8-20}$ d^{-1}
Tw= Mean water temperature in lagoon (°C), 8°C
n = Number of cells in series, 1 cell [Lagoon Lake].

Therefore,

$$C_f = 2.67X10^7 / (1 + 54((2.6)((1.19)^{(8-20)})) = 1.45 \text{ X } 10^6 \text{ CFU/L}$$

And,

$$C_f = 1.45 \text{ X } 10^6 / (1 + 50((2.6)((1.19)^{(8-20)})) = 8.47 \text{ X } 10^4 \text{ CFU/ L}$$

for Finger Lake, the second cell in series, where the detention time in the cell (d), is equal to 50 days [75,600 m^3 / 1,514 m^3/ day].

This value meets the licence's effluent quality standard of 1 X 10^5 CFU/L when the effluent is discharged in 54 days through Lagoon Lake and then 50 days through Finger Lake; and the lagoon water temperature is 8 °C, or warmer. The July average daily temperature is 11°C.

4.3 BOD_5 Reduction

Considering BOD_5 reduction, the following equation can be utilized to design a facultative wastewater treatment lagoon (*Natural Wastewater Treatment Systems*, Crites, Middlebrooks, Reed, 2006) and can provide an estimate of BOD_5 concentrations after the lakes given a design BOD_5 value from **Table 1**:

$$V = (3.5 \times 10^{-5})(Q)(La)(\theta^{(35-T)})(f)(f')$$

where

V = Lagoon volume (m^3),
Q = Influent flow rate (L/d), 269,600 L/d
La = Ultimate influent BOD_5 (mg/L), 400 mg/L
θ = Arhennius temperature correction coefficient, 1.085
T = Lagoon temperature (degrees C), 8°C
f = Algal toxicity factor, 1.0 for domestic wastes and many industrial wastes
f' = Sulfide oxygen demand, 1.0 for sulfate equivalent ion concentration of less than 500 mg/L

When Baker Lake is evaluated at 8°C,

$$V = (3.5 \times 10^{-5})(269{,}600)(400)(1.085^{(35-8)})(1)(1) = 34{,}155 \text{ m}^3$$

A pond depth of 1.5 meters is suggested for systems with significant seasonal variations in temperature and major fluctuations in daily flow. The volume (34,155 m^3) is obtained at Lagoon Lake when evaluating the area above the lake (above elevation 56.3 masl) to elevation 57.3 masl. Construction of the first berm directly downstream of Lagoon Lake and allowing the permafrost to permeate or migrate into the berm should provide adequate volume to address BOD_5 reduction. The BOD_5 removal efficiency is projected to be 80 to 90 percent based on unfiltered influent samples and filtered effluent samples. This BOD_5 removal efficiency will be adequate to meet the licence effluent quality standard of 80 mg/L prior to entering Airplane Lake.

4.4 Total Suspended Solids Reduction

Overland flow systems, such as the drainage from the Baker Lake "holding cell" to Lagoon Lake are generally effective in removing total suspended solids (TSS). However, the existing Holding Cell is small and the slope between it and Lagoon Lake is about 16 percent, which provides an increased risk of short-circuiting, channeling, and erosion; all which have occurred at the Baker Lake site. Increasing the size of the existing Holding Cell, the addition of a second holding cell and construction of relatively small berms between the holding cells and Lagoon Lake will create shallow ponds or terraces and divert flow, and these will aid in addressing TSS prior to Lagoon Lake. Additional removal of TSS will occur at Lagoon Lake. The berms around the holding cells should incorporate a liner.

4.5 Ammonia Reduction

The removal of pollutants such as ammonia in a treatment wetland is dependant on microbially-mediated aerobic transformations. Wetland plants provide ("leak") some oxygen to microbes in their root zones. When considering ammonia reduction, the following equation can be utilized to design the wastewater wetland area required (*Treatment Wetlands* Second Addition, Kadlec and Wallace, 2008):

$$C_{out}/C_{in} = 1/(1 + k/Pq)^{P}$$

where

C_{out} = outlet concentration, mg/L, = 32 mg/L
based on un-ionized ammonia fraction @ T = 11 °C and pH = 7.5
C_{in} = inlet concentration, mg/L, = 120 mg/L
based on 12 grams/day nitrogen (assumed to be ammonia) from
k = modified first order areal constant, m/yr [50th percentile] [@ T = 11 °C] = 10.7 m/yr
P = apparent number of tanks in series, = 3 (per cell) and 2 cells [Lagoon Lake area and Finger Lake],
q = hydraulic loading rate, m/d = Q/A, where Q = 1,514 m^3/d

Solving for q when

$$32/120 = 1 / ((1 + 10.7 / (3)(2)(q)^{(2)(3)})$$

q = Q / A = 7.236 m/yr = 0.0198 m/day, such that

A = Q / q = 1,514 m^3/day /0.0198 m/day

A = 76,365 m^2

The area of Lagoon Lake is 64,000 m^2 and Finger Lake is 52,000 m^2, totaling 116,000 m^2. Removal efficiency will be adequate to meet the effluent quality standard for un-ionized ammonia entering Airplane Lake.

4.6 Tundra Wetland Sewage Treatment

Available documentation indicates that the Hamlet of Baker Lake has been using the Tundra Wetland north of the community since it was constructed in 1980. Sewage is dumped directly from trucks onto the tundra in the area of the current Holding Cell and flows down a slope to Lagoon Lake, which flows to Finger Lake, which flows to Airplane Lake; that eventually flows to Baker Lake. Currently, sewage is discharged into the Holding Cell and the sewage seeps out through its north berm. Several studies of the treatment performance of the system have been undertaken since 1993, all concluding that the system successfully treats sewage effluent. Analytical results from effluent samples collected throughout the system demonstrated that the wetland is successfully treating sewage effluent to meet current and anticipated regulatory requirements.

The Water Licence requires compliance with the effluent quality standards be achieved at the discharge from the Sewage Treatment System, presently considered to be the discharge at the inlet of Airplane Lake (Compliance Point P3). Incorporation of these enhancements will ensure the system is a viable option to meet the Hamlet's sewage treatment requirements over the long term.

Signage will be posted along the boundaries of the system to advise residents of the wetland treatment area.

4.7 Evaluation of Design

A standard set of criteria have been established from which to evaluate the design option presented above. These criteria are outlined below:

Compliance: Achieve compliance with current and future effluent quality standards established by the Nunavut Water Board.

Long Term Needs: Meet the Hamlet's sewage treatment needs for a minimum 20 year period.

Practicality: The design must be able to be implemented with local expertise and provide a reasonable expectation of being successful.
Public Safety: The option should protect the health and safety of community residents.

Cost: The option should be cost effective from both a capital and operation and maintenance perspective.

4.7.1 Compliance

Compliance with effluent discharge standards are expected to be met with this design. Analytical results have demonstrated that the natural tundra wetland achieves compliance with effluent discharge standards. The purpose of these recommendations is to primarily address existing deficiencies and future needs.

4.7.2 Long Term Needs

Based on a desired decant of the storage lagoon in the summer/fall of each year, the lagoon should be sized with a storage capacity of 10 months for the 20 year planning horizon. This will require a capacity of 80,886 cubic meters for the year 2029.

The capacity of the tundra wetland to treat sewage over the long term can also be calculated based on loading rates and area of treatment. In the past, a commonly accepted hydraulic loading rate (wastewater flow rate over wetland area) for natural wetlands treating domestic sewage was 5 ha of wetland surface area per 1000 m^3/d of sewage flow introduced (expressed more commonly as 2 cm/d), but more recent studies indicate that up to 7 cm/d can be appropriate if conditions are right, some pre-treatment has occurred, and the wetland can be "engineered" to ensure maximum contact between the wastewater being treated and the vegetation/microbial biofilm matrices in the wetland (Knight et al., 1987). However, a more conservative recommendation is for 50 ha/1000 m^3/d (0.2 cm/d) for municipal wastewaters (Kadlec & Knight, 1996), especially where cold weather conditions are encountered and there is untreated ammonia nitrogen in the wastewater being treated.

Based on the conservative natural wetland sizing criteria of 50 ha/1000 m^3/d (0.2 cm/d), the minimum size of a natural wetland to treat the 2029 annual sewage generation rate (98,411 cubic meters or 270 cubic meters per day) would be 13.5 hectares. With the proposed berm construction and the tundra wetland area defined as illustrated in **Figures 3 and 4** in Appendix A, the boundary of the existing and proposed holding cells, the Tundra Wetland treatment system (including Lagoon Lake and Finger Lake and the areas between the holding cells and Lagoon Lake, and between Lagoon Lake and Finger Lake) encloses an area of approximately 135,000 square meters of which 69,000 square meters are shallow bodies of water (Lagoon Lake and Finger Lake) and 66,000 square meters are boggy areas. Based on these calculations and assumptions, the proposed Tundra Wetland Sewage Treatment System has sufficient area to treat wastewater for the next 20 years.

4.7.3 Practicality

The existing treatment system is currently in use and has an uneven floor with bedrock outcrops. Construction of berms in a manner to allow permafrost to aggrade into the berms to provide an impervious barrier is a practical solution.

Limited improvements are proposed for the Tundra Wetland System. A fencing project has been tendered. Signage will be installed along the boundaries of the wetland and new berms will be constructed. The berms on the holding cells will incorporate a geotextile liner. The other berms will be constructed such that permafrost will permeate or migrate into the berms and present impervious barriers. Installation of signage and berm construction can be carried out by local contractors.

4.7.4 Public Safety

Installation of a fence, construction of a second holding cell, improvements to the existing Holding Cell and the construction of new berms perpendicular to wastewater flow to allow Lagoon Lake to operate as a storage and treatment lagoon will allow sewage to be contained for a ten month period and will provide for a more managed discharge. Discharged effluent should meet effluent discharge standards at Compliance Point P3 (inlet to Airplane Lake). The public will have limited opportunity to come in contact with sewage effluent under this option.

The Tundra Wetland option provides continuous discharge from the Holding Cell and Lagoon Lake during the period of the year when ambient temperatures are at or above freezing temperatures (approximately two months). During the remainder of the year, sewage will freeze in the lagoon and be discharged upon snowmelt. Analysis of effluent samples indicates that the wastewater flow immediately outside the Holding Cell contains high concentrations of fecal coliforms. However, these concentrations decline relatively quickly with distance from the cell. The risk to public health and safety with this option is considered low as residents are well aware of the location of the wetland treatment area and it is to be fenced.

4.7.5 Cost Summary

Given the limited infrastructure resources available in Nunavut, cost is a very important factor in evaluating options.

Some general observations are presented here for consideration. Clay is probably not readily available. Even if it were available, it is not known whether local sources of it would be suitable as liner material. The volume of clay required is proportional to both the area required to be lined and the hydraulic conductivity of the clay material. Geotextile liners will be more practical. Installation of liners in the holding cells will require the purchase, transport, and installation of synthetic liner material and the placement of material to anchor and protect the liner. Construction of flow attenuation berms to promote permafrost aggradation will require considerable volumes of coarse gravel material. All of the construction items are considered to have high capital costs. Ongoing operation and maintenance costs will involve annual maintenance and repair of the berms, holding cells and the sewage discharge locations; and monitoring of permafrost aggradation.

Development of the Tundra Wetland treatment system will require the preparation and installation of signage. The berms will be constructed of locally available material, incorporating an imported synthetic liner. The construction cost estimate for this option is presented in **Table 5**:

Table 5: Conceptual Design Construction Cost Estimate

ITEM	UNITS	ESTIMATED QUANTITY	UNIT PRICE	AMOUNT
Flow Attenuation Berm No. 1				
Coarse Gravel, 50 - 75mm, Length = 90m	m^3	612	$	$
Flow Attenuation Berm No. 2				
Coarse Gravel, 50 - 75mm, Length = 175m	m^3	3,063	$	$
Flow Attenuation Berm No. 3				
Coarse Gravel, 50 - 75mm, Length = 240m	m^3	1,882	$	$
Flow Attenuation Berms				
Coarse Gravel, 50 - 75mm, Length = 245m	m^3	490	$	$
Expand Holding Cell				
Plastic Liner	m^2	800	$	$
Liner Trenching	LM	90	$	$
Coarse Gravel, 50 - 75mm, Length = 90m	m^3	990	$	$
Sand	m^3	270	$	$
Additional Holding Cell				
Plastic Liner	m^2	800	$	$
Liner Trenching	LM	90	$	$
Coarse Gravel, 50 - 75mm, Length = 90m	m^3	990	$	$
Sand	m^3	270	$	$

<u>Miscellaneous</u>				
Mobilization	LS	1	$	$
Warning Signs	Each	4	$	$
Improve Existing Discharge Location	LS	1	$	$
New Sewage Discharge Location	LS	1	$	$
Anticipated Construction Cost				$

The estimated construction cost is expected to be approximately **$**, not including contingencies. Annual operation and maintenance costs will be very low, and will be related to repair of signage/fence and maintenance of the berms, cells and discharge locations.

5.0 SCHEMATIC DESIGN

The current Baker Lake sewage treatment facility consists of a Holding Cell that discharges to a natural tundra wetland. Improvements to the wetland system will optimize its treatment capacity such that the Tundra Wetland Sewage Treatment System can effectively treat the Hamlet's sewage for a 20-year period in compliance with applicable legislation.

The proposed Tundra Wetland System begins at the current and proposed discharge sites. Sewage haulers will alternately transport untreated sewage to the existing sewage Holding Cell and a new holding cell. Wastewater will be deposited into the holding cells to allow initial settling. The holding cells begin the treatment process. The north, (downstream) sides of the holding cells will require impervious berms. Initially, a gravel material will be placed. A 150 mm thick layer of sand will be placed on top of this gravel layer. An impermeable high density polyethylene (60 mil thick, textured HDPE) liner then will be placed on the sand layer The liner will be anchored into the inside of the berm and into the native ground material as best as practical and possible; however, shallow bedrock may limit the anchor trench depth in some areas. The HDPE liner will then be covered by another 150 mm thick layer of sand. The entire berm will then be covered with 300 mm of coarse gravel to provide erosion control. The location of the holding cells is shown in **Figure 3** and a cross section of a holding cell berm is shown in **Figure 4** in Appendix A. By leaving the native ground material in place, a permafrost layer should build up over time and provide an impermeable layer to prevent water from flowing under the coarse gravel material.

Water will outlet through the holding cell berms at specified outlets and enter the tundra wetland. New flow attenuation berms are proposed between the holding cells and Lagoon Lake. The location of these seven, 35 meter long berms is shown in **Figure 3** and a cross section of a flow attenuation berm (Section B) is shown in **Figure 4** in Appendix A. The berms will be constructed on the native ground material and where practical will be located between bedrock outcrop areas. Flow currently travels in the areas between bedrock outcrops and the attenuation berms are intended to re-route and disperse the water so it does not enter Lagoon Lake at only one location. Coarse gravel will be placed on the ground to a height of 500 mm. The upstream sides of the berms will have a relatively flat 1 to 6 slope to reduce the potential for ice to build up which might potentially damage the berms.

Two new flow attenuation berms are proposed between Lagoon Lake and Finger Lake and a third berm is proposed between the solid waste disposal site and Finger Lake. The location for these three berms is shown in **Figure 3** and a cross section of the berms (Section A) is shown in **Figure 4** in Appendix A. These three berms will be constructed as described above, except upstream slope of each berm will have a steeper 1 to 3 slope and the berm top width will be 3 meters wide; as the berms located between the two lakes are intended to reduce the potential for ice to enter Finger Lake during the winter.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The Hamlet of Baker Lake has been disposing of its sewage at a location approximately 1.2 kilometers north of the Community. Previous investigations have confirmed that the Tundra Wetland System was successfully treating the sewage. The sewage is delivered to a detention (holding) cell but, the berms of this cell are not impervious, allowing water to seep from the detention cell onto the downstream Tundra Wetland in an uncontrolled manner.

The sewage disposal and treatment in Baker Lake is currently regulated by the Nunavut Water Board, under a Water Licence. Effluent quality standards prescribed in the licence require compliance at discharge from the “Sewage Disposal Facilities”, which is currently considered to be SNP Station P3 (the entrance to Airplane Lake). In support of its application to renew its Water Licence, the Hamlet of Baker Lake needs a sewage treatment system design that will allow it to achieve compliance with effluent quality standards.

NJWL evaluated the existing Tundra Wetland System to achieve compliance: repair of the detention cell and, enhancement of the Tundra Wetland. The Tundra Wetland System was selected as the preferred option for sewage treatment for the community. A preliminary design for enhancements to the system has been prepared. Upon approval of the preliminary design concept, NJWL will prepare construction drawings and tender documents for review by CGS.

6.1 Recommendations

It is recommended that:

1. The Tundra Wetland sewage treatment process continue at Baker Lake and that enhancements for this system be selected for formal implementation.
2. The preliminary design be advanced to the 50% complete design phase for further review.
3. An application to renew the Hamlet’s Water Licence, incorporating the enhanced Tundra Wetland sewage treatment system be prepared for submission to the Nunavut Water Board.
4. This report focuses on the sanitary wastewater at Baker Lake. However, the solid waste disposal facility has to be further addressed in the next design phase.

7.0 CLOSURE

This Report has been prepared by Nunami Jacques Whitford Ltd. for the sole benefit of the Department of Community and Government Services, Kivalliq Region, of the Government of Nunavut. This Report may not be relied upon by any other person or entity without the express written consent of Community and Government Services.

Any uses that a third party makes of this Report, or any reliance on decisions to be made based on it, are the responsibility of such third parties. Nunami Jacques Whitford Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this Report.

The conclusions presented represent the best judgment of Nunami based on current site conditions observed on the date cited within this Report. If any conditions become apparent that differ significantly from our understanding of conditions as presented in this Report, we request that we be notified immediately to reassess the conclusions provided herein.

We trust that the report meets your current requirements. Should you have any questions or concerns regarding the above, please do not hesitate to contact the undersigned.

Respectfully submitted,

NUNAMI JACQUES WHITFORD LTD.

Jeff Elliott
Project Engineer

Jim Higgins, Ph.D., P.Eng.
Chief Engineer

APPENDIX A

Drawings and Figures

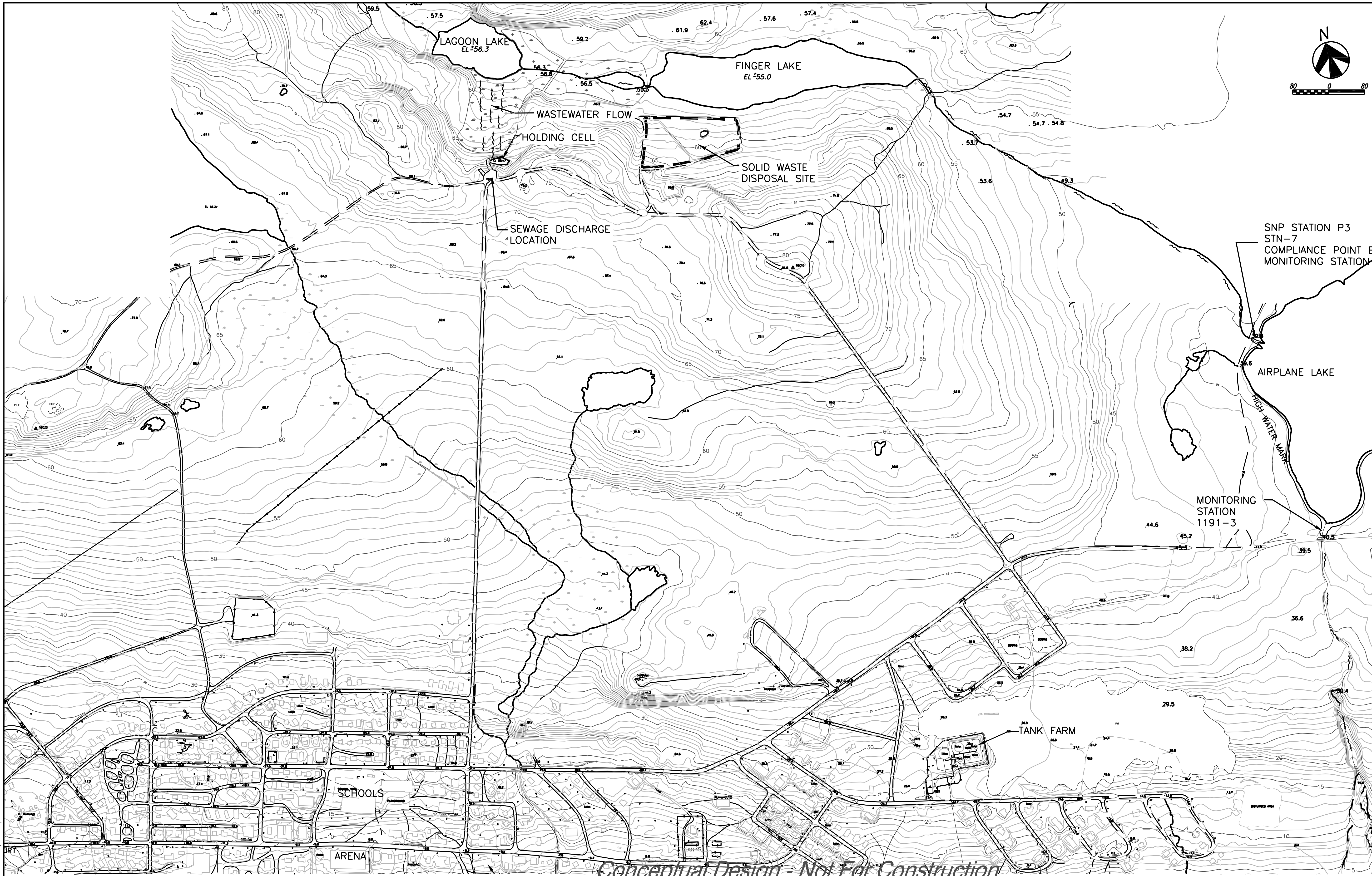
100 50 0 100 km

SCALE 1 : 5 000 000

*IMAGE REFERENCE: MAPART PUBLISHING, ALBERTA ROAD ATLAS, 200

**THIS DRAWING WAS ORIGINALLY CREATED IN COLOUR.

Jacques Whitford NAWE	SCALE: 1 ; 5 000 000 DATE: 14/11/06 DRAWN BY: SEA APPROVED BY:	CLIENT : COMMUNITY AND GOVERNMENT SERVICES GOVERNMENT OF NUNAVUT TITLE : SITE LOCATION PLAN QAMANI'TUAQ, NU	DRAWING NO. 1



Plot Date: 27 October 2008 By Henkel, Marc

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Rev	Date	Description
2	10/24/08	Schematic Design
1	5/01/08	Issue for Review
0	3/19/08	Issue for Review

GOVERNMENT OF NUNAVUT DEPARTMENT OF COMMUNITY AND GOVERNMENT SERVICES
PROPOSED SYSTEM IMPROVEMENTS
BAKER LAKE SEWAGE SYSTEM
QAMANTI'TUAQ, NU

Site Plan
Existing Conditions

Figure 2

Figures.dwg

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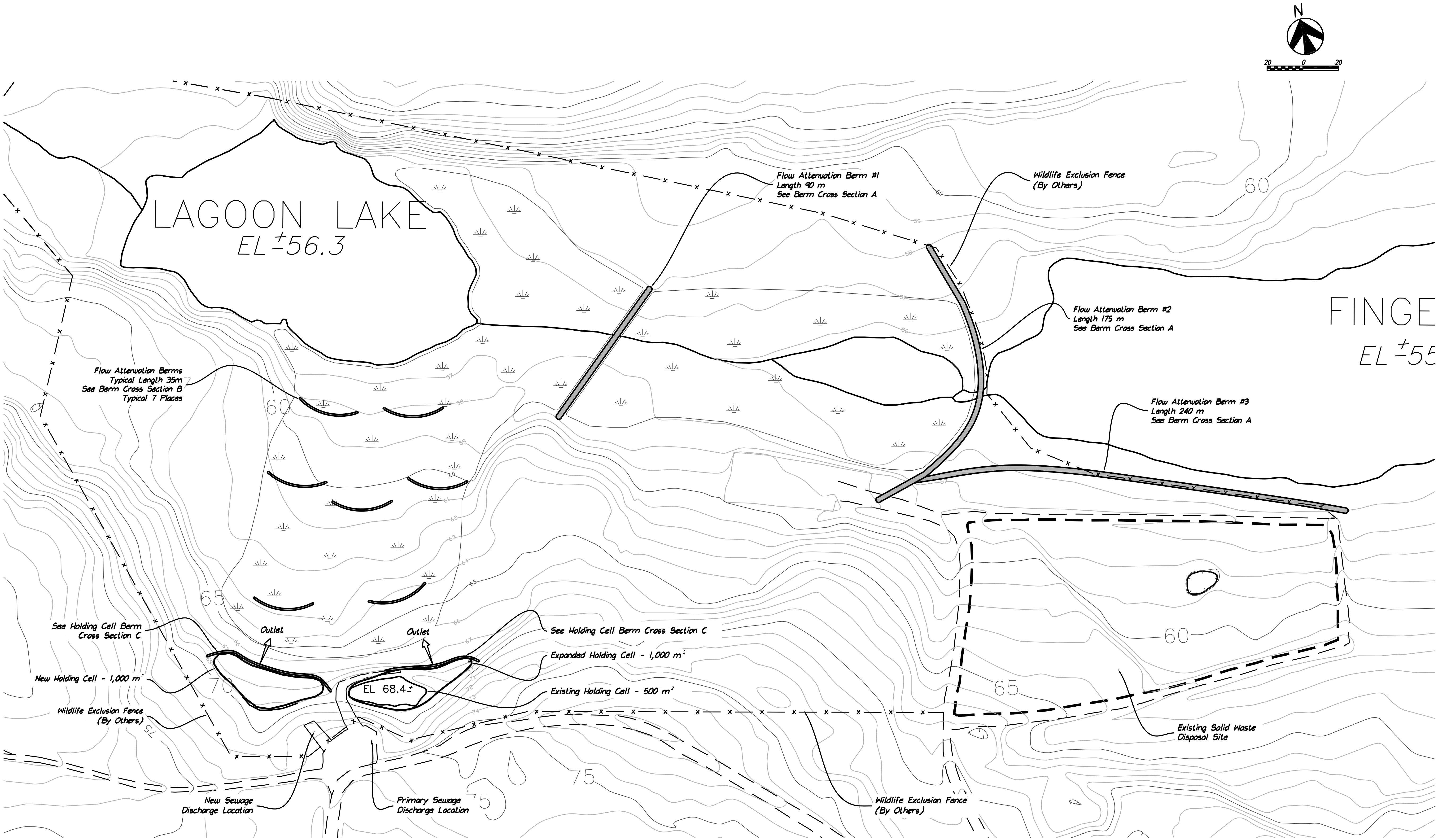

Conceptual Design - Not For Construction

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PROPOSED SYSTEM IMPROVEMENTS
BAKER LAKE SEWAGE SYSTEM
QAMANTI'TUAQ, NU

Proposed Design Layout

Figure 3

Figures.dwg

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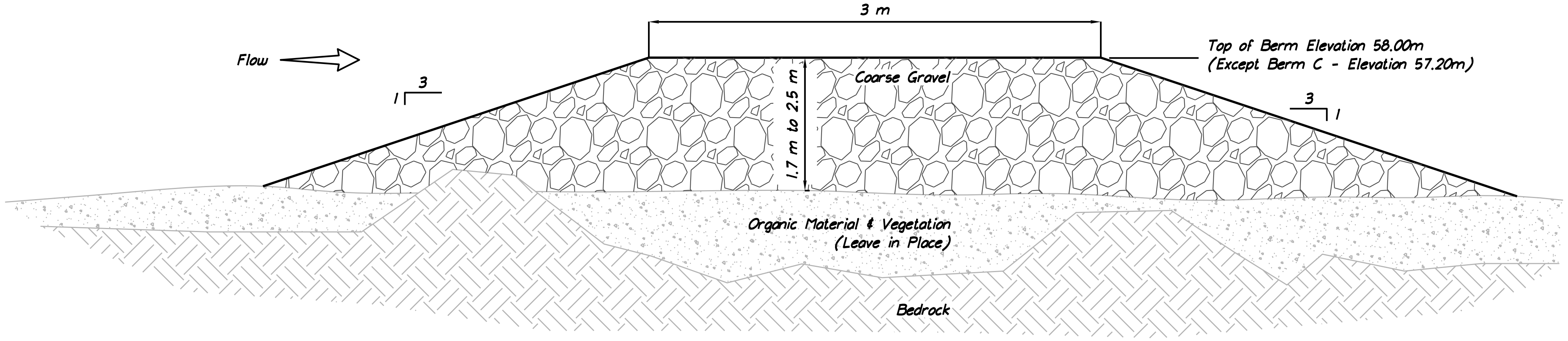
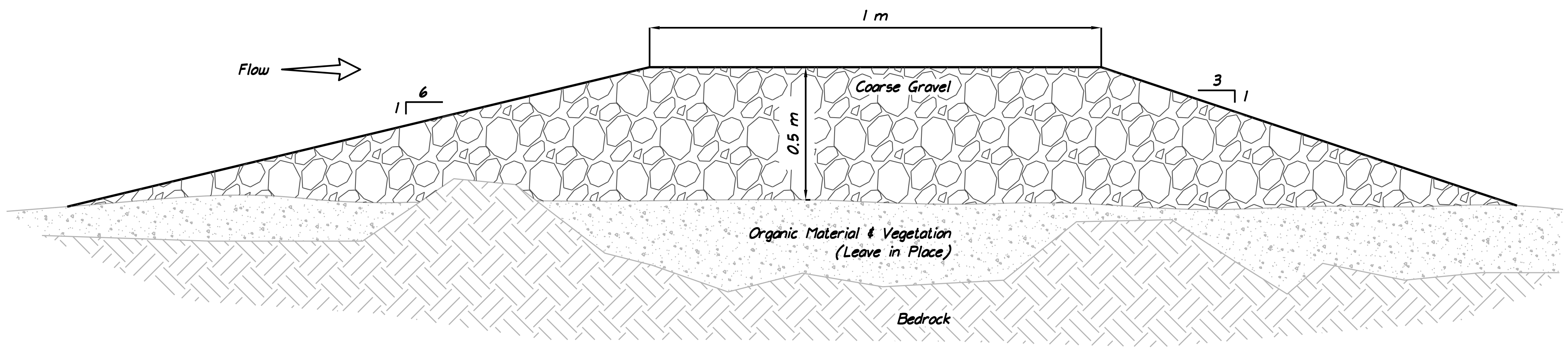
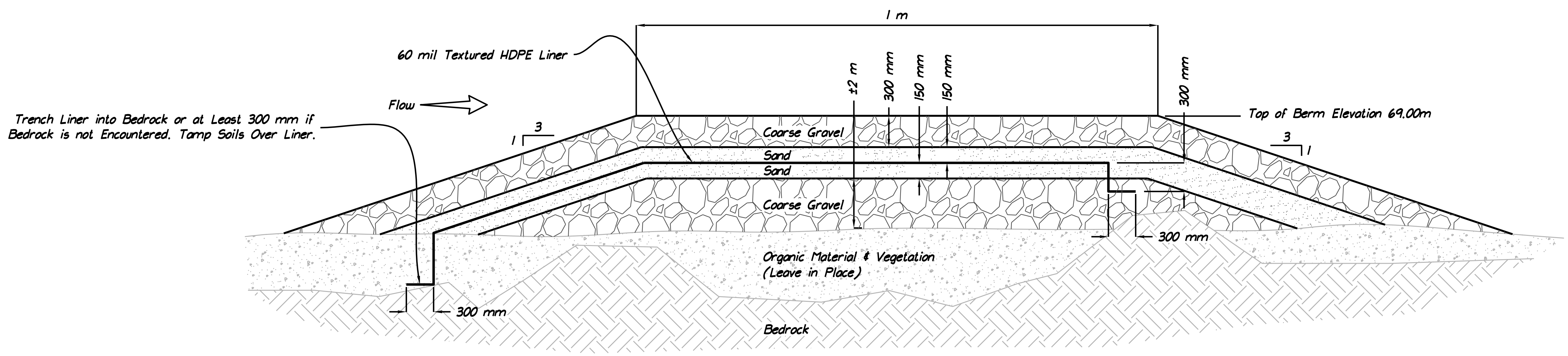


Typical Flow Attenuation Berm #1 Thru #3 Cross Section - A



Typical Flow Attenuation Berm Cross Section - B



Holding Cell Berm Cross Section - C

Conceptual Design - Not For Construction

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Proposed Berm Cross Sections

Figure 4

Figures.dwg

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